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OPTICAL CONTACTING FOR GRAVITY PROBE STAR TRACKER

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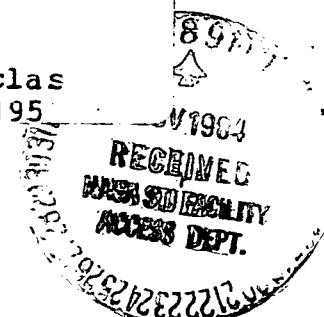
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16. ABSTRACT A star-tracker telescope, constructed entirely of fused silica elements optically contacted together, has been proposed to provide submilliarc-second pointing accuracy for Gravity Probe. First this report provides a bibliography on optical contacting; the bonding of very flat, highly polished surfaces without the use of adhesives. Then results are presented from preliminary experiments on the strength of optical contacts including a tensile strength test in liquid helium. The report emphasizes the need for further study to verify an optical contacting method for the Gravity Probe star-tracker telescope.					
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TECHNICAL MEMORANDUM

OPTICAL CONTACTING FOR GRAVITY PROBE STAR TRACKER

I. INTRODUCTION

It has been proposed that the star-tracker telescope for Gravity Probe be constructed entirely of fused silica elements optically contacted together. It is hoped that the required submilliarc-second pointing accuracy can be achieved with this material of small thermal expansion coefficient. However, optical contacting (the bonding of very flat, highly polished surfaces without the use of adhesives) has been treated largely as an art. Little is known about the performance of the bond, particularly at the liquid helium temperature environment of the proposed star-tracker telescope. A procedure is needed that, on the first try, will result in a precisely aligned bond of predictable strength and durability.

The results of an extensive literature search on optical contacting are reported in Section II. In Sections III and IV, preliminary work on optical contacting and tensile strength measurements at liquid helium temperatures are described, respectively. Then in Section V, the attempted acoustic vibration test of the test model telescope and the resulting squeeze tests are described. Finally, in Section VI suggestions are made for more extensive experimentation needed to determine a reliable procedure for optical contacting.

II. SUMMARY OF LITERATURE SEARCH

The results of the literature search for articles related to optical contacting are found in the bibliography. The first two entries are reports from previous Gravity Probe studies which suggested that further study of optical contacting was needed. The other articles are listed under headings of optical contacting, surface cleaning, and van der Waals dispersion forces.

It is generally thought that van der Waals dispersion forces between atoms and molecules are largely responsible for the adhesion of flat highly-polished fused-silica surfaces. However, the theory becomes very complex for real surfaces with contamination, roughness, and deviation from flatness. Experiments have measured the attraction force between fused silica surfaces down to about 100 Å. Measured tensile strengths of fused silica surfaces in optical contact have been reported to be in the range of 100 to 200 lb/in.² at room temperature. Although the theory and experiments suggest that dispersion forces are sufficient to explain these tensile strengths, the quantitative prediction of optical contact tensile strengths between real surfaces is difficult.

What has not been found in the literature was any mention of quantitative strength test measurements at liquid helium temperatures. It is not clear that the surface cleaning and optical contacting procedures mentioned result in the required precisely aligned bonds with predictable strengths on the first try. There is no guarantee that one can pull apart a bad bond without damaging the surfaces. Finally, there is no reliable way reported for verifying the strength of the bond by inspection.

III. OPTICAL CONTACTING PROCEDURE

An optical contact requires a smooth flat surface that is free from contamination. In this section, roughness (texture) and overall flatness measurements of the optical flats to be contacted are described. Then surface cleaning methods and contacting procedures are reported.

The optical flats were 1-in. diameter, 1/2-in. thick, fused silica discs specified to have less than $\lambda/20$ (10^{-6} in.) rms deviation from flatness. The first set of flats were coated with aluminum in order to measure roughness on the BRDF (Bidirectional Reflectance Distribution Function) machine. Scattering from the back surface would make the measurement invalid. The BRDF machine uses the scattering of a helium neon laser beam approximately 2 mm in diameter, to measure the surface texture of materials. Measurements were taken at several points on each optical flat tested. Surface roughness (texture) values of the tested samples ranged from 15 to 30 Å rms deviation. The flats were also measured for their overall planar surface flatness on the Twyman-Green interferometer. The aluminum coating was not required but made these measurements easier. Two interferograms, oriented 90 deg apart, were made for each of the sample flats tested. These interferograms were then measured on the Zygo machine which produced histogram pictures of the surfaces and gave the rms deviation from flatness for each interferogram. Values obtained were on the order of $\lambda/40$, or smaller, which were better than the $\lambda/20$ flatness values specified by the supplier.

The cleaning of the optical flat surfaces prior to mating them is an integral part of the contacting procedure. A typical method is as follows:

- 1) Wash with diluted detergent solution and lint free cloth.
- 2) Rinse thoroughly. End with a distilled water rinse.
- 3) In a class 100 flow bench clean with distilled, filtered acetone (and/or ethyl alcohol) and lint free cloth. Pull acetone (and/or ethyl alcohol) soaked lens tissue between the flats.
- 4) Pull dry lens tissue between the flats.
- 5) Overlap the flats slightly. Align them parallel to each other by observing white light fringe pattern. There should only be a few fringes across the overlap. Gently slide the flats over each other to remove remaining particles and/or air. The last fringe colors are strawyellow, white, grey, and, finally, no visible reflection. End up with the straw yellow separation or less.
- 6) Press down slightly to check for the interference pattern around remaining contamination. If observed, go back to step 1. Otherwise, press down at an edge to start the contact across the flat. Push the contact across by applying pressure if necessary. The contacted area has no visible reflection at the interface. Uncontacted islands may be visible. The flats may still be pried apart carefully if this is done before most of the interface is contacted.
- 7) If desired, separate the flats by heating the pair followed by rapid cooling of one flat in cool water.

The literature includes many variations involving cleaning in various detergents, organic solvents, and acids under more or less controlled conditions. Actually, the purity of the fused silica and the machining, polishing and storage procedures may be critical as well. The above method of cleaning is simple, and on the small flats mentioned above, it worked as well or better than more elaborate methods tried. However, this method might be difficult to use in constructing a reliable flight telescope.

Since the first set of flats had been coated with aluminum, the coating had to be removed first. A 10 percent sodium hydroxide solution got all of the visible aluminum off the surface. However, if the detergent wash in step 1 of the above method was replaced by a soaking in hot concentrated nitric acid, contacting seemed much easier with the flats initially coated with aluminum and stripped with NaOH. The NaOH may leave a residual amount of aluminum, which is removed by the nitric acid. It would not take much contamination to make optical contacting difficult.

This contacting procedure and apparently the other contacting procedures reported in the literature do not always result in good bonds on the first try. Repeated attempts increase the risk of damaging the surfaces.

It has been suggested by D. E. Davidson (see item 2 of the bibliography) that heating the contacted pieces to about 300°F for at least two weeks would improve the bond by removing trapped moisture and other volatile contaminants from the bond. Ideally, the bond then should be sealed around the edges or not be exposed to such contamination thereafter.

IV. TENSILE STRENGTH TESTS IN LIQUID HELIUM

The apparatus used for the strength tests (Fig. 1a) consisted of a long narrow frame containing a load cell at the top and a fixture at the bottom which held the optical bond samples. Tightening a bolt at the top applied tension to the bond samples through the calibrated load cell. The fixture was given some freedom to twist to reduce the possibility that any small misalignment would cause the bond to be pried apart. Failing to give enough freedom here would probably reduce the measured pull strength. The optically contacted pairs of flats were bonded with RTV silicone adhesive either to fused silica or invar (65 percent iron, 35 percent nickel) end pieces which fit into the fixture (Figs. 1b,c). RTV silicone adhesive sealant was the only adhesive found that was strong enough at liquid helium temperature and did not crack the fused silica due to a difference in the thermal coefficients of expansion. Various epoxy formulations had been tried. Invar has a very low thermal expansion coefficient, is not likely to break, and is easier to use than fused silica in fabricating the end pieces. Although the RTV and/or invar may stress the glass, the thermal stress might not propagate all the way to the optical bond.

Pull tests started with slow immersion of the bottom fixture into liquid nitrogen and then liquid helium. The fixture was immersed slowly in order to reduce the thermal shock on the samples. Tension was then applied by gradual tightening of the bolt at the top until the test sample failed.

Most of the optical bonds tested failed upon immersion in liquid nitrogen or helium. This may be due to contamination (moisture, etc.) in the contact, thermal shock on the fused silica, or perhaps the difference in thermal expansion between the fused silica and the RTV and/or invar end pieces. The three contacts which did

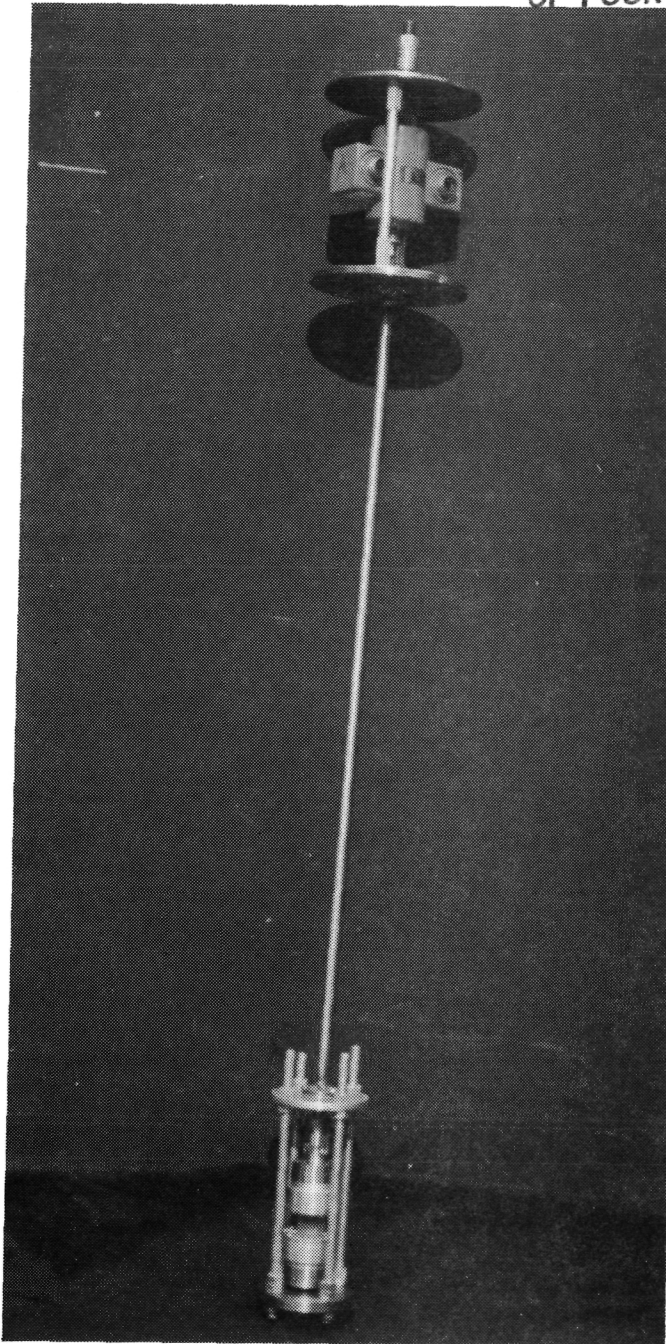


Figure 1a. Apparatus used in optical bond tensile strength test.

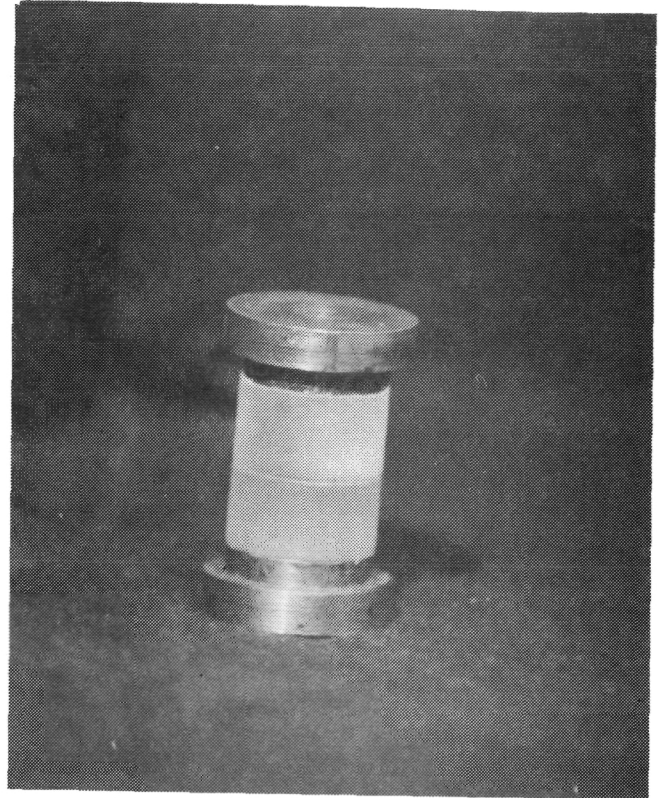


Figure 1b. Pair of optically contacted flats bonded to invar end pieces.

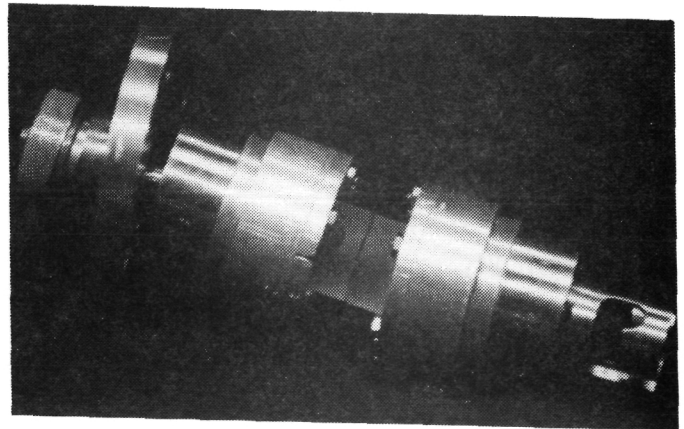


Figure 1c. Bottom fixture holding test sample shown above.

not fail on immersion pulled apart at pressures of 400 to 600 psi which is much larger than the 100 to 200 psi reported at room temperature.

V. TELESCOPE TEST MODEL AND SQUEEZE TESTS

The 2-ft-long gravity probe test model telescope (Fig. 2) was contacted with fused silica parts by D. E. Davidson. It included a 6-in. diameter tube fritted to an 8 $\frac{1}{4}$ -in. diameter 2-in. thick base. Another 6-in. tube was optically contacted to the other side of the base. The other end of this second tube was optically

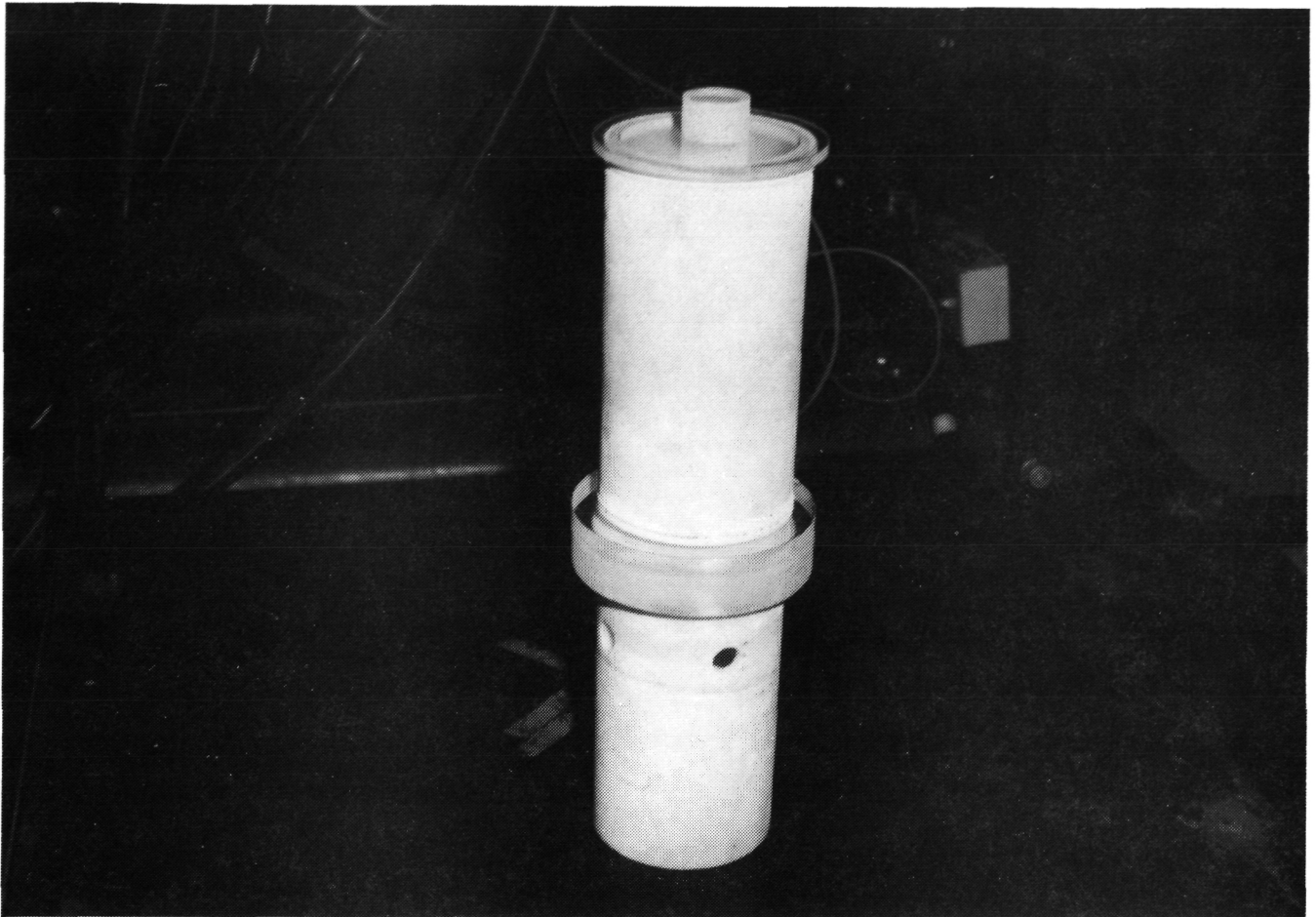


Figure 2. Gravity probe test model telescope.

contacted to a 3/8-in. thick, 7-1/2-in. diameter plate to which a 2-in. diameter, 1-in. thick disc was optically contacted. After being optically contacted by D. E. Davidson, the test model was placed vertically in an oven at 280°F for four weeks. The test model was then placed in the acoustic vibration facility to simulate the stresses encountered during shuttle flight. The test model was to be held horizontally by a 2-in. wide metal split ring around the 2-in. thick telescope base. An elastic material had been bonded to the inside of the split ring. The optical contact between the base and the 6-in. telescope tube failed a few minutes after the model had been turned horizontal but before the ring was fully tightened down on the base (Fig. 3). The fritted joint was vibrated in planes parallel and perpendicular to the tube axis without failing.

It was first thought that the telescope model optical contact may have failed because of stresses produced by the squeeze force from the split-ring holder. In order to investigate that possibility, two pairs of the 1-in. diameter, 1/2-in. thick fused silica pieces were optically contacted, and one flat of each pair was squeezed in a small split ring (Fig. 4). The two samples tested required average pressures around the edge of approximately 4200 and 7700 psi to break the bonds. To apply that pressure on the test model telescope base would have required about 1300 and 2400 in. pounds of torque, respectively, applied to the screws of its hold-down fixture. It is unlikely that anywhere near this much torque was applied by partial tightening with a 4-in. allen wrench. Although the geometry is different in the two cases, this seems to suggest that a good bond would not have been broken by the compression alone. Note that the test model had always been held vertical until it

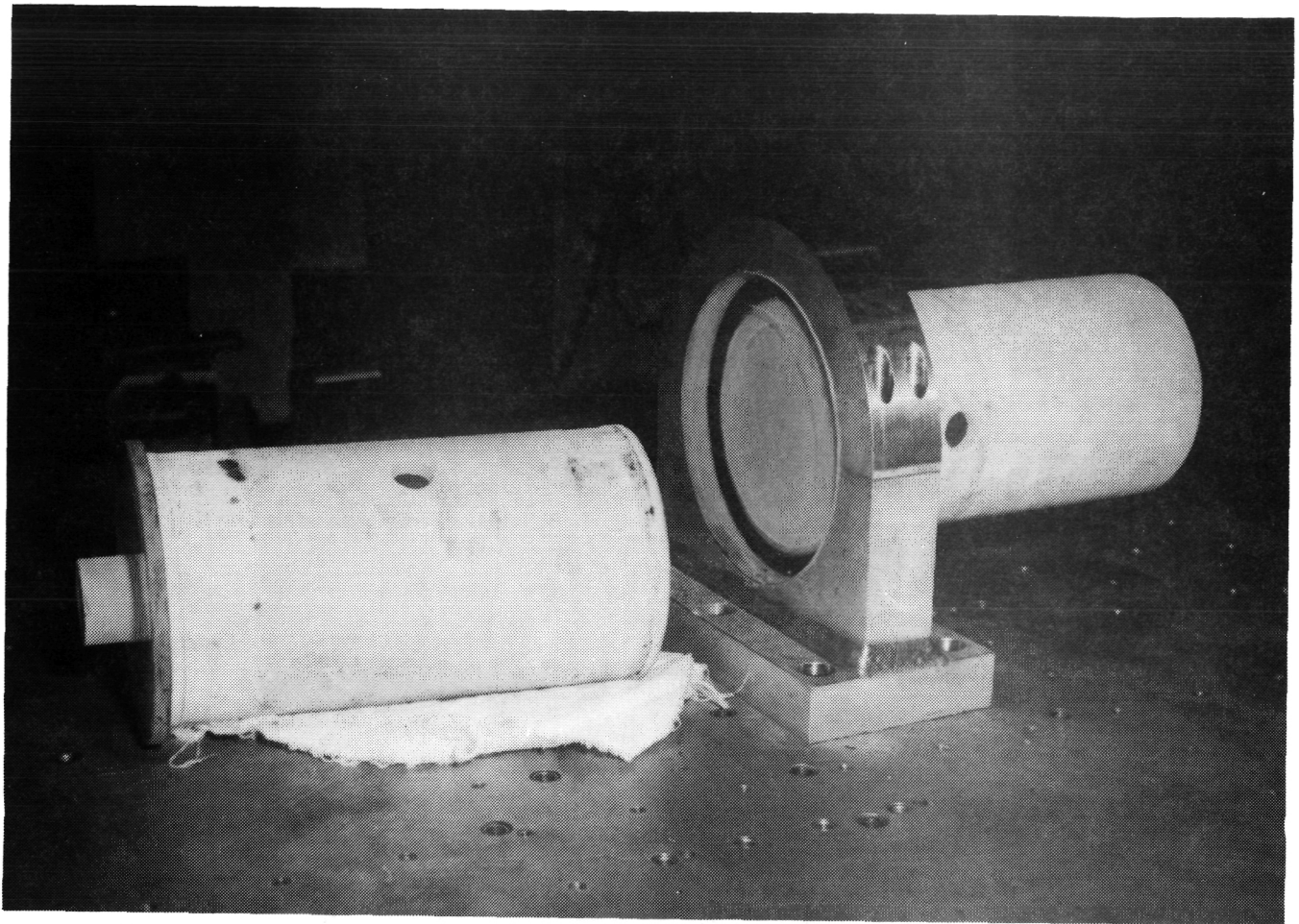
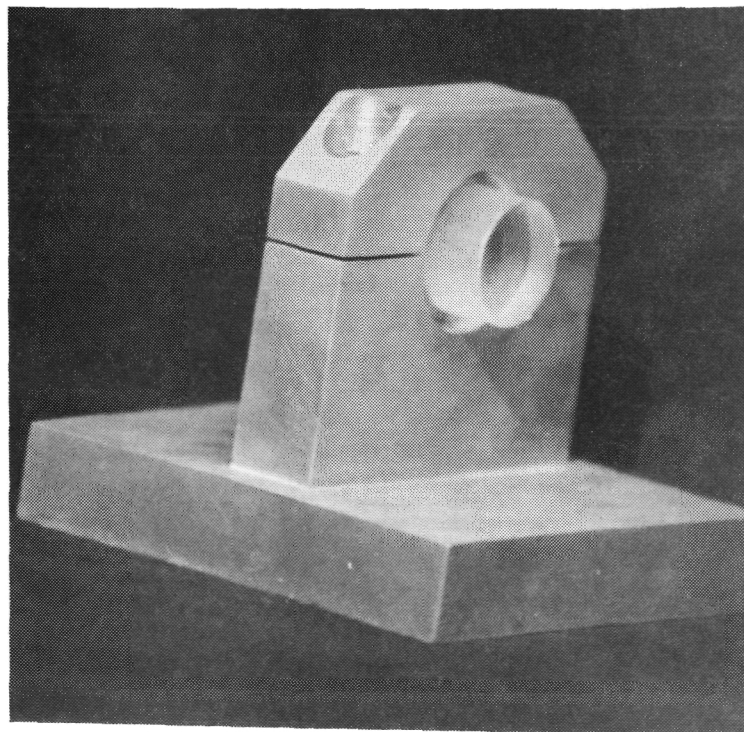


Figure 3. Failure of the optical contact at the test model base when mounted in the acoustic vibration test apparatus.



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Figure 4. Squeeze test fixture holding one flat of an optically contacted pair of flats.

was placed in the vibration test fixture a few minutes before the bond failed. D. E. Davidson had earlier recommended fritted joints at the base which must support the quartz tubes.

VI. RECOMMENDATIONS

Much more experimental work is required to verify optical contacting for the Gravity Probe telescope construction. To continue the study, specialized equipment needs to be developed to clean the surfaces and contact them in precise alignment in a continuously controlled environment. Many samples must be produced, contacted and strength tested under precisely defined conditions until a reliable procedure is found. The liquid helium test facility must allow gradual cool down and no contact with the helium. Finally, studies must show that many pieces can be contacted together in precise alignment to construct the flight telescope.

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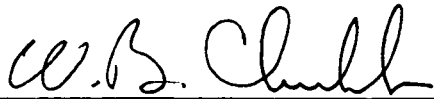
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APPROVAL

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The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.



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